

0891

PB 206 734

REMOTE SENSING OF POLLUTANTS

ANNUAL REPORT

June 30, 1971

to

Environmental Protection Agency

Air Pollution Control Office

Research Triangle Park, North Carolina

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from

National Oceanic and Atmospheric Administration

Environmental Research Laboratories

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BIBLIOGRAPHIC DATA SHEET		1. Report No. APTD-0891	2.	3. Recipient's Accession No.
4. Title and Subtitle Remote Sensing of Pollutants - Annual Report		5. Report Date June 30, 1971		
7. Author(s)		6.		
9. Performing Organization Name and Address National Oceanic and Atmospheric Administration Environmental Research Laboratories Boulder, Colorado		8. Performing Organization Rept. No.		
		10. Project/Task/Work Unit No.		
		11. Contract/Grant No.		
12. Sponsoring Organization Name and Address Environmental Protection Agency Air Pollution Control Office Division of Chemistry Physics Research Triangle Park, North Carolina 27711		13. Type of Report & Period Covered		
15. Supplementary Notes		14.		
16. Abstracts Research results obtained during FY 71 are summarized on quantitative infrared spectra of pollutant gases such as CO, O ₃ , HCl, SO ₂ , NH ₃ , and HNO ₃ ; on analyzing long path infrared spectra by digital means for atmospheric gas concentrations; on scattering cross section measurements for SO ₂ and NO; and on literature search and consultative services in atmospheric spectroscopy. Explanations and reviews of the particular results are illustrated by samples of the voluminous transmission tables and graphs supplied separately. The developed information is crucial for proper interpretation of remote sensing field measurements of pollutant concentrations in both source and ambient situations. () ←				
17. Key Words and Document Analysis. 17a. Descriptors Air pollution Infrared spectroscopy Carbon monoxide Ozone Hydrochloric acid Sulfur dioxide Ammonia Nitric acid Data processing Light scattering Nitrogen oxide (NO)				
17b. Identifiers/Open-Ended Terms				
17c. COSATI Field/Group 13B				
18. Availability Statement Unlimited		19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 52	
		20. Security Class (This Page) UNCLASSIFIED	22. Price	

REMOTE SENSING OF POLLUTANTS

ABSTRACT

This report summarizes ^{are summarized} research results obtained during FY 71 on quantitative infrared spectra of pollutant gases such as CO, O₃, HCl, SO₂, NH₃ and HNO₃; on analyzing long path infrared spectra by digital means for atmospheric gas concentrations; on scattering cross section measurements for SO₂ and NO; and on literature search and consultative services in atmospheric spectroscopy. Explanations and reviews of the particular results are illustrated by samples of the voluminous transmission tables and graphs supplied separately. The developed information is crucial for proper interpretation of remote sensing field measurements of pollutant concentrations in both source and ambient situations.

REMOTE SENSING OF POLLUTANTS

1. Introduction and Summary

This report reviews support activities of the Atmospheric Spectroscopy Group, ERL/NOAA, for the Air Pollution Control Office, EPA, for the year ending June 30, 1971. The EPA funding for this cooperative effort was \$60,000, authorized by a letter of November 23, 1970 from Dr. John T. Middleton, EPA, to Dr. Wilmot Hess, ERL/NOAA.

The project study areas include (1) quantitative infrared spectra of atmospheric pollutant constituents, (2) least-squares fitting procedures to analyze infrared field data for constituent concentrations, (3) laboratory laser scattering studies of pollutant gases, and (4) literature search and consulting services. Results of the studies have been transmitted to EPA at various times throughout the year. These results are the significant end products of the project, but are impractical to include in their entirety as part of this annual report because of their bulk. Samples of the generated information are included as appendices to this report.

The data generated are important for the monitoring of gaseous air pollutants by both long path infrared and Raman backscatter means. In principle, an infrared spectrum contains information on the concentration of absorbing molecules in the optical path. In order to extract this information, the spectra of the molecules in the path, both natural and pollutant, must be known, and one must have a method for fitting the known spectra to the field spectrum. This project has generated essential information on reference spectra and fitting programs. Similarly, to evaluate and calibrate Raman backscatter systems for monitoring source emissions, scattering cross

sections and depolarization ratios for molecules of interest have been measured during this project.

In the four study areas outlined, the project has produced the following information: (1) digitized 1 cm^{-1} resolution infrared absorption spectra, for three to five different representative concentrations, over the spectral ranges 740 to 1430 cm^{-1} and 1824 to 3333 cm^{-1} , for the gases H_2O , CO_2 , CO , O_3 , N_2O , CH_4 , HCl , SO_2 , NH_3 and HNO_3 at 296 K and 760 torr total pressure; (2) a least-squares spectrum fitting program successfully tested in preliminary form on synthetic data; (3) Raman scattering cross sections and depolarization ratios for SO_2 and NO at four different incident photon energies; and (4) a volume of selected literature reprints on the infrared absorption characteristics of pollutant gases and numerous written proposal evaluations for APCO, Division of Chemistry and Physics and the Office of Research Grants.

These results are discussed in detail in the following sections.

2. Quantitative Infrared Spectra

A. Introduction

Long path infrared spectra of the atmosphere contain information on the gaseous composition in the path. Particularly, spatially averaged pollutant concentrations are in principle available from this field data. In order to analyze the field data APCO is now preparing to measure, quantitative reference spectra for the gases in the path must be known at the instrumental resolution used for the field spectra. Unfortunately, spectra in the literature are deficient in that they are taken at low total gas pressures (not representative of the real atmosphere), they exhibit insufficient

resolution (1 cm^{-1} resolution is to be used in the field to increase specificity of the measurement), and/or they do not include quantitative intensity information (required to determine concentrations).

The transmission, absorption coefficient and concentration of a gas sample are related by the well-known expression,

$$T(\nu) = e^{-k(\nu)cL}$$

where T is the transmission, k is the absorption coefficient, c is the gas concentration in molecules/ cm^3 and L is the path length. If an experimental measurement is made with an instrumental bandwidth wider than the actual linewidth (which is less than approximately 0.1 cm^{-1} at atmospheric pressure) this expression no longer holds. Instrumentally averaged absorption coefficient, $\bar{k}(\nu)$, then becomes an experimentally unknown function also of the absorber density cL . The transmission at a given wavenumber and the concentration are then related in a complicated way, depending on the unresolved character of the spectral lines. Spectra at various cL products are required as reference spectra. Interpolation for differing cL is approximately valid, but extrapolation is not. Incidentally, if $k(\nu)$ is established for five points in every resolution element, extrapolation followed by five point averaging is approximately valid.

For fitting field spectra, the spectrum of both natural and pollutant gases must be considered.

B. Calculated Spectra

For the gases H_2O , CO_2 , CO , O_3 , N_2O , CH_4 and HCl we have calculated spectra for three to five concentration · path length products (in units of

molecules/cm²) at 296 K and 760 torr total pressure. All known absorptions have been included for the regions 1824 to 3333 cm⁻¹ and 740 to 1430 cm⁻¹. In the near infrared region T(v) is sampled and recorded every 0.6 cm⁻¹. For the middle infrared, the sampling interval is every 0.2 cm⁻¹. This data format is chosen to be compatible with the data format chosen by APCO for the field data.

An instrumental bandwidth of 1 cm⁻¹ was used for the calculated spectra. Appendix A shows samples of graphical and tabulated data for short regions of CO, HCl and O₃. The tabulated data actually extends (on larger output paper) to five concentrations, and is available on punched card and magnetic tape format as well. Complete volumes of graphical and tabulated data for these gases have been supplied to Dr. Barnes separately as part of this project.

These spectral tabulations are input reference data for the field analysis program. The digital data character is essential for the automated processing, and is an additional advantage of the data developed during this project.

Line parameters for HCl³⁵ and HCl³⁷ in natural isotope abundance were computed as part of this project. The resulting spectrum (partially shown in Appendix A) demonstrates the power and applicability of the line parameter approach.

In HCl, for example, the computed line positions fit experiments to better than .01 cm⁻¹, and the intensity to better than 2%. By comparing the generated spectra to literature references (discussed later) it is obvious that literature spectra are not directly applicable to the APCO problem.

C. Experimental Measurements

For SO_2 , NH_3 and HNO_3 the theoretical analyses are not sufficiently developed to calculate transmissions. Data taken digitally with a 3/4 meter Ebert spectrometer with 1 cm^{-1} resolution (at 1000 cm^{-1}) instrumental bandpass is processed to the sampling interval and digital format discussed under calculated spectra. This process includes digital filtering to maximize signal-to-noise, wavelength correction to eliminate scan system irregularities and conversion to an independent variable scale linear in wavenumber.

The data is taken at 296 K and 760 torr total pressure to be compatible with the calculated spectra. Details of the experimental method, including notes on equipment and data processing systems, are discussed in a previous quarterly report. Since these spectra are ground state absorptions and not "hot bands" (excited initial state), temperature variations of $\pm 10\%$ in the atmosphere have little effect on the spectra. A significant and accepted assumption at the low concentrations used, and at 1 cm^{-1} instrumental bandpass, is that self-broadening and nitrogen-broadening parameters are approximately the same for these gases. This allows simulation of a low concentration, long path system by a higher concentration, shorter path length laboratory absorption cell.

Samples of the digitized data for SO_2 and HNO_3 are also shown in Appendix A. The complete set of graphs and printout is supplied to APCO separately. Note that this data is in an identical format to the calculated spectra, and that data is available on magnetic tape and punched cards as well.

3. Field Data Analysis Program

A. Introduction

The field infrared spectrum is a complicated result of the overlapping absorption spectra of all the atmospheric molecules in the optical path. An approach to deconvoluting the spectra is to perform a multi-dimensional least squares fit of the reference spectra to the field spectrum. A total transmission over a spectral interval is calculated using a best estimate of the atmospheric composition. The error matrix (from a comparison of calculated and actual spectra) is analyzed to correct the constituent concentrations and iteratively determine the composition of the field atmosphere.

Application of the program to real field data raises questions of signal-to-noise in the field spectrum and the effect of unknown gases for which no reference spectrum exists. Even in the 8 to 12 μm "window" water vapor has a significant continuum absorption for long path lengths. Fluctuations in water vapor content will introduce uncorrelated noise of a presently unknown magnitude. Similarly, additional research is needed to determine the effect of additional unknown constituents. Instrumental (detector) noise may also adversely affect the fitting procedure.

B. Results

The main fitting program is given in Appendix B. Operational subroutines are not included in this brief example. A preliminary version of the program (with 2.5 cm^{-1} data spacing) in card format, complete with annotated listing and reference spectra, has been separately supplied to APCO. This program has successfully fit a six-component trial spectrum made of a mixture of

reference spectra. The effects of noise on the spectrum have not been simulated.

Appendix B also gives samples of total atmospheric absorption spectra, taken with the sun as a source and normalized by the assumption of a 6000 K thermal source for the solar spectral output. This digitized data is of a format suitable for a test of the program, in absence of other field data, but time limitations have prevented analysis of the spectrum yet.

The fitting program has subroutines for extensive checking of input data and for output spectrum plotting if desired. The program has also been modified to accept the newly generated reference data and fit on a 0.2 cm^{-1} grid over 740 to 1430 cm^{-1} and on a 0.6 cm^{-1} grid over 1824 to 3333 cm^{-1} . In general, the program relies on a gradient-projection method of fitting. The error functions discourage selection of concentrations outside a reasonable transmission range.

C. Summary

Although potential problems exist in the fitting of real, noisy data to the reference spectra, the least squares fitting program developed during this project period shows reasonable promise (and more promise than any other technique considered here) of analyzing infrared spectra for atmospheric composition. Additional testing and refinement is indicated for next year.

4. Laboratory Laser Scattering Studies

A. Introduction

Raman lidar, the optical analog of radar, may be useful for monitoring source emissions and other air pollution detection applications where spatial resolution is important. This is in contrast to long path absorption techni-

ques which yield a spatial average, and to passive infrared emission techniques which lack the flexibility of an active illuminator and are subject to interference problems.

Raman scattering cross sections are small, and field experiments so far have at best had limited success. The laboratory scattering studies of this project are designed to (1) measure pollutant scattering cross sections (relative to nitrogen as an internal standard) and (2) study photon energy dependent variations in relative cross section.

Quantitative cross section information is needed for feasibility studies of Raman Lidar systems and as a calibration value to interpret results of any field measurements in terms of actual amounts of pollutants in the source sample. Energy-dependent cross section effects must be understood to find pump wavenumbers where, for a particular gas, the cross section is relatively large so that range and concentration limits of lidar systems may be extended. This involves questions of resonance Raman and atmospheric pressure fluorescence effects, if they indeed exist.

B. Analysis System

Considerable development has gone into a digital data analysis system to rapidly and accurately compute relative Raman scattering cross sections and depolarization ratios. The main program, less lengthy subroutines, is shown for example in Appendix C. This program is operational and has been successfully checked against approximate hand calculations. Such an analysis system permits consistent measurements of quantitative cross sections and energy-dependent cross section effects.

The analysis philosophy is shown in the "geocor" sketch of Appendix C.

Signal-to-noise is maximized by collecting over as large a solid angle as possible. Necessary corrections to obtain the A and B scattering parameters from I_x and I_y are made by the program.

A block diagram of the apparatus used to obtain the digital Raman data is also shown in Appendix C. The program corrects the spectral curve, input on paper tape, for a linearly sloping baseline and integrates the resulting signal. A sophisticated intensity calibration scheme, using tandem Ba SO_4 Lambert's-law scattering surfaces to convert a standard of spectral irradiance to a low-intensity standard of spectral radiance, is an important part of the analysis method. The standard lamp power curve is fit to 1.8% rms calibration difference by a three-parameter thermal radiation expression in the program.

C. Results of Cross Section Measurements

Table 1 shows the results of experimental Raman scattering measurements. The new data analysis system was used in all cases. Data for SO_2 are consistent with less complete data given in the literature (Fouche and Chang, Appl. Phys. Letters 18, 579 (1971)). Similarly, data for NO are consistent with UV measurements (Leonard, J. Appl. Phys. 41, 4238 (1970)). These results are still preliminary in that additional experiments are scheduled to check the validity of the measurements.

The SO_2 and NO cross sections are not large enough to suggest easy field experiments. The cross sections are absolutely necessary to convert field scattering intensity measurements to N_2 /pollutant mixing ratio, however. While water vapor is not a pollutant, cross section results for H_2O are shown to indicate the importance of a proper selection of laser wave-

number to maximize Raman return for a particular constituent. Theoretical understanding of the Raman effect is as yet insufficient to explain these incident photon energy effects.

We are now prepared to analyze the cross section behavior of other interesting molecules, especially NO_2 and hydrocarbon vapors, which have shown promise of large scattering cross sections.

5. Literature Search and Consulting

A. Introduction

This cooperative research program benefits from and incorporates significant previous work in atmospheric absorption and scattering spectroscopy. The Atmospheric Spectroscopy Group maintains an extensive literature file on the spectra of natural and pollutant gases. Over twenty journals are regularly scanned, as well as numerous reports, abstract services and book lists.

Personnel from the Group also aid APCO/EPA in technical advice concerning proposals from industry and general information on spectroscopic problems.

B. Results

A volume of selected information from the literature has been sent separately. Spectra of C_2H_2 , NH_3 , C_6H_6 , HCl , H_2S , HNO_3 , NO , NO_2 , Peroxyacetyl Nitrate (PAN) and SO_2 were discussed in these references. These reported sources were chosen from many available because they contained the most useful information for APCO's purposes. The only significant information since the date of the literature review volume is that the CO_2 continuum in the 800 to 1250 cm^{-1} region is negligible at

atmospheric partial pressures.

Intercomparison of the literature spectra and spectra developed during this project shows how the spectrum of a particular constituent changes character as the instrumental resolution and buffer gas pressure is varied. This emphasizes the need for quantitative reference spectra taken under conditions simulating as closely as possible the field experiment. The literature shows a surprising lack of data of the type needed by APCO for analysis of field data.

Literature information has been helpful for sample preparation techniques and qualitative spectral information as a check of present results.

NOAA personnel have given written evaluations of industry Raman sensing proposals and numerous university grant applications through ORG of APCO.

6. Future Project Direction

We expect that significant effort is required to test the field data fitting program and train APCO personnel in the use of the program. Experiments with various signal-to-noise ratios and components for which no reference spectra exist are necessary to explore the performance envelope of the program and develop operational confidence.

Infrared reference spectra will be available to APCO based on line parameter data only. Experimental work is better done on the APCO FTS-14 interferometric spectrometer than at NOAA. Details of expected line parameters for NO and SO₂, as well as development of a digital "degrade" program to modify high-resolution experimental data for particular field comparison, have been discussed in a separate memo to Mr. John Nader.

Exploratory laboratory work should continue on the fluorescent/Raman scattering of NO_2 and hydrocarbon vapors because these gases have a high probability of exhibiting large scattering cross sections (based on some preliminary observations). If large cross sections are observed, there should be useful applications to source monitoring for NO_2 and hydrocarbons.

We will continue to consult with APCO on spectroscopic problems of mutual interest.

Table 1

Measured Relative Raman Cross Sections ($\sigma_{N_2} = 1$)

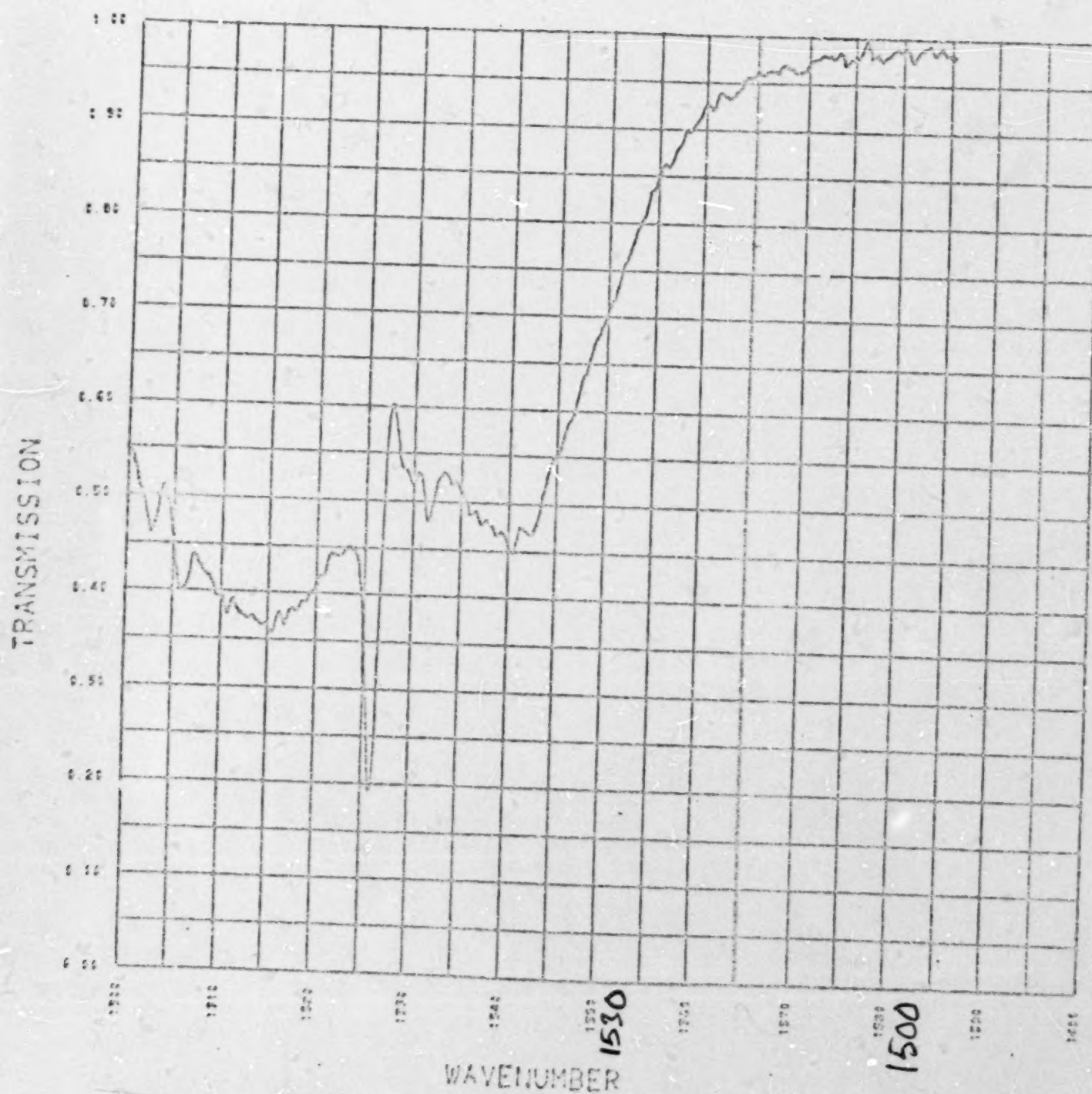
Gas	Laser Wavenumber, cm^{-1}	Relative Cross Section	Depolarization
SO_2	20 981 (476.5nm)	5.7	.05
	20 487 (488.0nm)	5.5	.06
	20 135 (496.5nm)	5.8	.04
	19 430 (514.5nm)	6.1	.05
NO	20 981	.36	.11
	20 487	.36	.10
	20 135	.34	.11
	19 430	.39	.08
H_2O	20 981	2.5	
	20 487	1.9	
	19 430	3.3	

APPENDIX A

A-1

A-1

NITRIC ACID AT 3 TORR PARTIAL PRESS



NOT REPRODUCIBLE

A-2
A-4

TRANSMISSION SPECTRUM FOR NITRIC ACID AT 3.0 TORR

HAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1294.8	0.6369637	1295.0	0.6359146
1295.4	0.6196604	1295.6	0.6160094
1296.0	0.6095242	1296.2	0.6042692
1296.6	0.6028656	1296.8	0.6044015
1297.2	0.6005477	1297.4	0.5944253
1297.8	0.5759542	1298.0	0.5709550
1298.4	0.5775858	1298.6	0.5809021
1299.0	0.5758973	1299.2	0.5715837
1299.6	0.5645171	1299.8	0.5588747
1300.2	0.5486897	1300.4	0.5456930
1300.8	0.5321424	1301.0	0.5224141
1301.4	0.5060786	1301.6	0.5019677
1302.0	0.4858691	1302.2	0.4747450
1302.6	0.4609951	1302.8	0.4637409
1303.2	0.4858280	1303.4	0.4982529
1303.8	0.5096699	1304.0	0.5053131
1304.4	0.4900066	1304.6	0.4789973
1305.0	0.4404412	1305.2	0.4198159
1305.6	0.4004562	1305.8	0.4021031
1306.2	0.4047593	1306.4	0.4088870
1306.8	0.4313827	1307.0	0.4387354
1307.4	0.4326727	1307.6	0.4277233
1308.0	0.4237339	1308.2	0.4196557
1308.6	0.4162052	1308.8	0.4142753
1309.2	0.4030257	1309.4	0.3966909
1309.8	0.3947398	1310.0	0.3941440
1310.4	0.3777868	1310.6	0.3756906
1311.0	0.3908056	1311.2	0.3929691
1311.6	0.3823211	1311.8	0.3782892
1312.2	0.3764775	1312.4	0.3748434
1312.8	0.3719124	1313.0	0.3731262
1313.4	0.3733169	1313.6	0.3708414
1314.0	0.3665841	1314.2	0.3654793
1314.6	0.3666218	1314.8	0.3645973
1315.2	0.3571463	1315.4	0.3600531
1315.8	0.3744135	1316.0	0.3790821
1316.4	0.3700099	1316.6	0.3657449
1317.0	0.3769537	1317.2	0.3821905
1317.6	0.3818983	1317.8	0.3809464
1318.2	0.3858882	1318.4	0.3898489
1318.8	0.3905365	1319.0	0.3926967
1319.4	0.4005524	1319.6	0.4024038
1320.0	0.4149368	1320.2	0.4188744
1320.6	0.4182897	1320.8	0.4242910
1321.2	0.4398457	1321.4	0.4430120
1321.8	0.4416298	1322.0	0.4406112
1322.4	0.4412407	1322.6	0.4431878
1323.0	0.4494209	1323.2	0.4505184
1323.6	0.4482137	1323.8	0.4471087
1324.2	0.4354376	1324.4	0.4191565

TRANSMISSION SPECTRUM FOR NITRIC ACID AT 3.0 TORR

WAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1324.8	0.3735159	1325.0	0.3409326
1325.4	0.2523713	1325.6	0.2130127
1326.0	0.2017273	1326.2	0.2522243
1326.6	0.4229214	1326.8	0.5008027
1327.2	0.5885168	1327.4	0.6013644
1327.8	0.5914530	1328.0	0.5766143
1328.4	0.5453686	1328.6	0.5361635
1329.0	0.5339702	1329.2	0.5315599
1329.6	0.5196158	1329.8	0.5180875
1330.2	0.5264782	1330.4	0.5301507
1330.8	0.5179004	1331.0	0.5031877
1331.4	0.4795521	1331.6	0.4811770
1332.0	0.5015419	1332.2	0.5104895
1332.6	0.5231348	1332.8	0.5269653
1333.2	0.5299453	1333.4	0.5281947
1333.8	0.5195330	1334.0	0.5177360
1334.4	0.5201233	1334.6	0.5183584
1335.0	0.5089715	1335.2	0.5058342
1335.6	0.4956647	1335.8	0.4877751
1336.2	0.4889207	1336.4	0.4913905
1336.8	0.4819322	1337.0	0.4772090
1337.4	0.4795790	1337.6	0.4820741
1338.0	0.4787492	1338.2	0.4744933
1338.6	0.4670505	1338.8	0.4665869
1339.2	0.4698851	1339.4	0.4674572
1339.8	0.4599613	1340.0	0.4554002
1340.4	0.4477842	1340.6	0.4513989
1341.0	0.4696431	1341.2	0.4750747
1341.6	0.4722371	1341.8	0.4696088
1342.2	0.4677394	1342.4	0.4676334
1342.8	0.4742840	1343.0	0.4821136
1343.4	0.5030425	1343.6	0.5113996
1344.0	0.5276707	1344.2	0.5365120
1344.6	0.5471580	1344.8	0.5497369
1345.2	0.5554988	1345.4	0.5614112
1345.8	0.5774211	1346.0	0.5830835
1346.4	0.5909258	1346.6	0.5967130
1347.0	0.6133561	1347.2	0.6242587
1347.6	0.6363794	1347.8	0.6392301
1348.2	0.6541734	1348.4	0.6634123
1348.8	0.6744219	1349.0	0.6789133
1349.4	0.6880112	1349.6	0.6920629
1350.0	0.7056809	1350.2	0.7117883
1350.6	0.7189240	1350.8	0.7260751
1351.2	0.7429776	1351.4	0.7480724
1351.8	0.7596284	1352.0	0.7653243
1352.4	0.7769584	1352.6	0.7843913
1353.0	0.7965235	1353.2	0.7993836
1353.6	0.8072716	1353.8	0.8166733
1354.2	0.8329205	1354.4	0.8350457

TRANSMISSION SPECTRUM FOR NITRIC ACID AT 3.0 TORR

WAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1354.8	0.8404612	1355.0	0.8477174
1355.4	0.8618314	1355.6	0.8634465
1356.0	0.8598814	1356.2	0.8609621
1356.6	0.8722933	1356.8	0.8773609
1357.2	0.8827661	1357.4	0.8881585
1357.8	0.8981625	1358.0	0.8979170
1358.4	0.8999624	1358.6	0.9031164
1359.0	0.9079446	1359.2	0.9114572
1359.6	0.9214635	1359.8	0.9252812
1360.2	0.9264754	1360.4	0.9248740
1360.8	0.9252961	1361.0	0.9306444
1361.4	0.9396165	1361.6	0.9390827
1362.0	0.9360792	1362.2	0.9345459
1362.6	0.9349662	1362.8	0.9376859
1363.2	0.9425830	1363.4	0.9453183
1363.8	0.9544292	1364.0	0.9566809
1364.4	0.9559040	1364.6	0.9574753
1365.0	0.9616405	1365.2	0.9601209
1365.6	0.9592196	1365.8	0.9623048
1366.2	0.9637556	1366.4	0.9610890
1366.8	0.9608748	1367.0	0.9646240
1367.4	0.9697661	1367.6	0.9684510
1368.0	0.9665026	1368.2	0.9659159
1368.6	0.9623632	1368.8	0.9611712
1369.2	0.9613643	1369.4	0.9634389
1369.8	0.9688136	1370.0	0.9709098
1370.4	0.9743931	1370.6	0.9752993
1371.0	0.9767403	1371.2	0.9784069
1371.6	0.9799876	1371.8	0.9797896
1372.2	0.9801395	1372.4	0.9794095
1372.8	0.9778829	1373.0	0.9797844
1373.4	0.9825825	1373.6	0.9780886
1374.0	0.9712000	1374.2	0.9744555
1374.6	0.9778573	1374.8	0.9774051
1375.2	0.9795192	1375.4	0.9804743
1375.8	0.9897440	1376.0	0.9955979
1376.4	0.9868211	1376.6	0.9784287
1377.0	0.9805431	1377.2	0.9825845
1377.6	0.9767421	1377.8	0.9755711
1378.2	0.9792575	1378.4	0.9811840
1378.8	0.9851996	1379.0	0.9870492
1379.4	0.9874891	1379.6	0.9866598
1380.0	0.9874508	1380.2	0.9883057
1380.6	0.9824548	1380.8	0.9771963
1381.2	0.9778920	1381.4	0.9825526
1381.8	0.9873612	1382.0	0.9881044
1382.4	0.9911747	1382.6	0.9920207
1383.0	0.9858860	1383.2	0.9822341
1383.6	0.9865854	1383.8	0.9898980
1384.2	0.9851008	1384.4	0.9821119

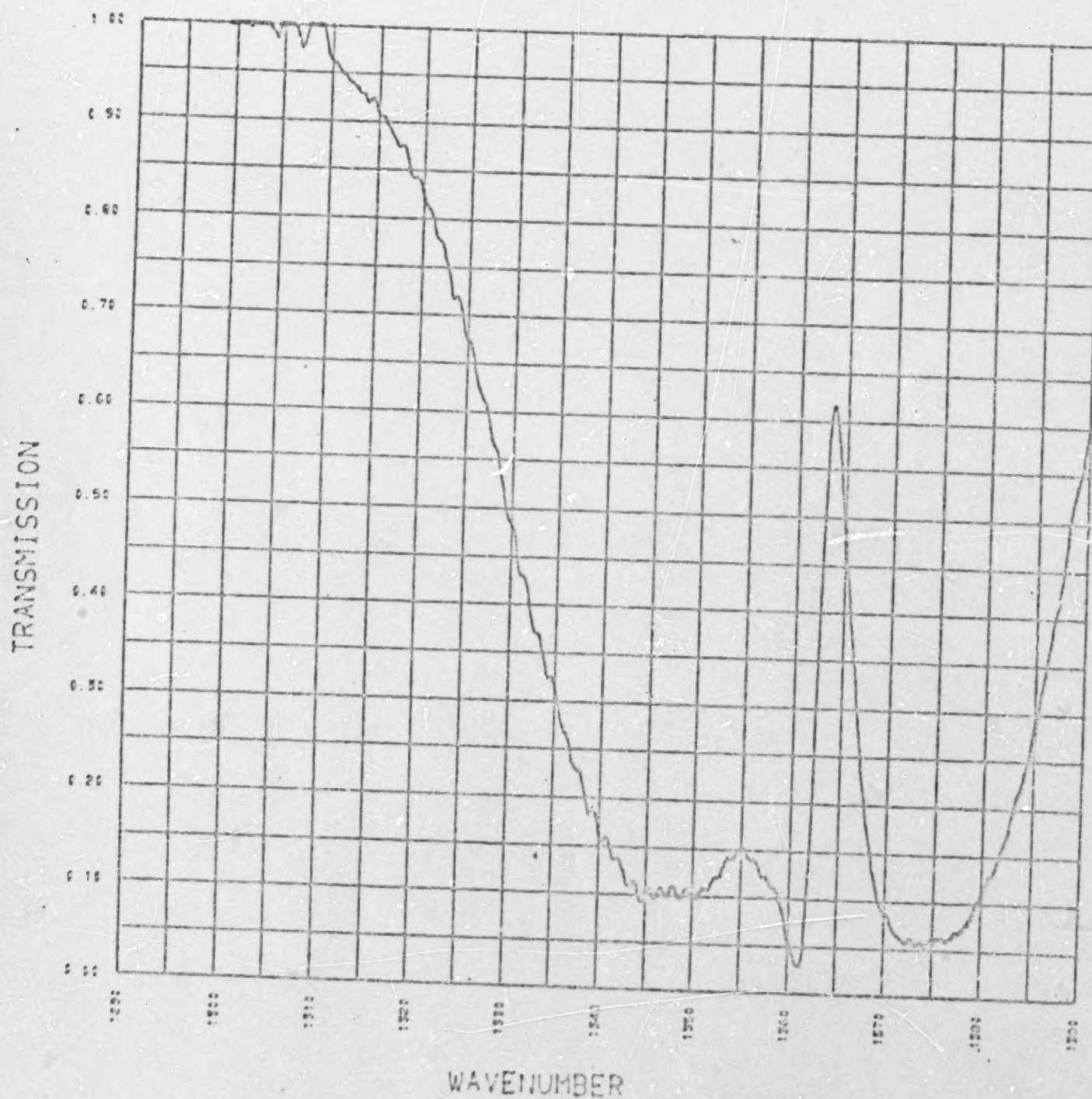
TRANSMISSION SPECTRUM FOR NITRIC ACID AT 3.0 TORR

WAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1384.8	0.9821645	1385.0	0.9813165
1385.4	0.9804405		

A-6

A-6

S02 10 TORR



NOT REPRODUCIBLE

A-7

A-7

TRANSMISSION SPECTRUM FOR SULPHUR DIOXIDE AT 10 TORR

WAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1299.2	1.0184670	1299.4	1.0127410
1299.8	1.0052850	1300.0	1.0024330
1300.4	1.0030830	1300.6	1.0095930
1301.0	1.0080060	1301.2	1.0023420
1301.6	1.0052450	1301.8	1.0166600
1302.2	1.0186340	1302.4	1.0192510
1302.8	1.0306980	1303.0	1.0221860
1303.4	0.9988104	1303.6	0.9960690
1304.0	0.9897408	1304.2	0.9866437
1304.6	1.0121630	1304.8	1.0236890
1305.2	1.0155380	1305.4	1.0098740
1305.8	1.0011150	1306.0	0.9982159
1306.4	0.9887156	1306.6	0.9807784
1307.0	0.9807563	1307.2	0.9900181
1307.6	1.0258540	1307.8	1.0440820
1308.2	1.0439570	1308.4	1.0299310
1308.8	1.0084230	1309.0	0.9993397
1309.4	0.9768454	1309.6	0.9696752
1310.0	0.9641466	1310.2	0.9628216
1310.6	0.9566618	1310.8	0.9530956
1311.2	0.9499082	1311.4	0.9484572
1311.8	0.9426565	1312.0	0.9410753
1312.4	0.9386394	1312.6	0.9354164
1313.0	0.9312806	1313.2	0.9312741
1313.6	0.9243202	1313.8	0.9205439
1314.2	0.9254493	1314.4	0.9257372
1314.8	0.9132999	1315.0	0.9082859
1315.4	0.9069644	1315.6	0.9038279
1316.0	0.8957952	1316.2	0.8924704
1316.6	0.8849791	1316.8	0.8813015
1317.2	0.8745774	1317.4	0.8759699
1317.8	0.8761863	1318.0	0.8668554
1318.4	0.8486267	1318.6	0.8437792
1319.0	0.8422980	1319.2	0.8426632
1319.6	0.8358006	1319.8	0.8285729
1320.2	0.8144783	1320.4	0.8110167
1320.8	0.8054239	1321.0	0.7980942
1321.4	0.7809673	1321.6	0.7786418
1322.0	0.7754243	1322.2	0.7677248
1322.6	0.7528123	1322.8	0.7436477
1323.2	0.7199030	1323.4	0.7162525
1323.8	0.7192490	1324.0	0.7138763
1324.4	0.6910049	1324.6	0.6808727
1325.0	0.6741500	1325.2	0.6707772
1325.6	0.6527459	1325.8	0.6418279
1326.2	0.6242454	1326.4	0.6178493
1326.8	0.6102401	1327.0	0.6055933
1327.4	0.5863319	1327.6	0.5750184
1328.0	0.5631403	1328.2	0.5586549
1328.6	0.5396176	1328.8	0.5285189

TRANSMISSION SPECTRUM FOR SULPHUR DIOXIDE AT 10 TORR

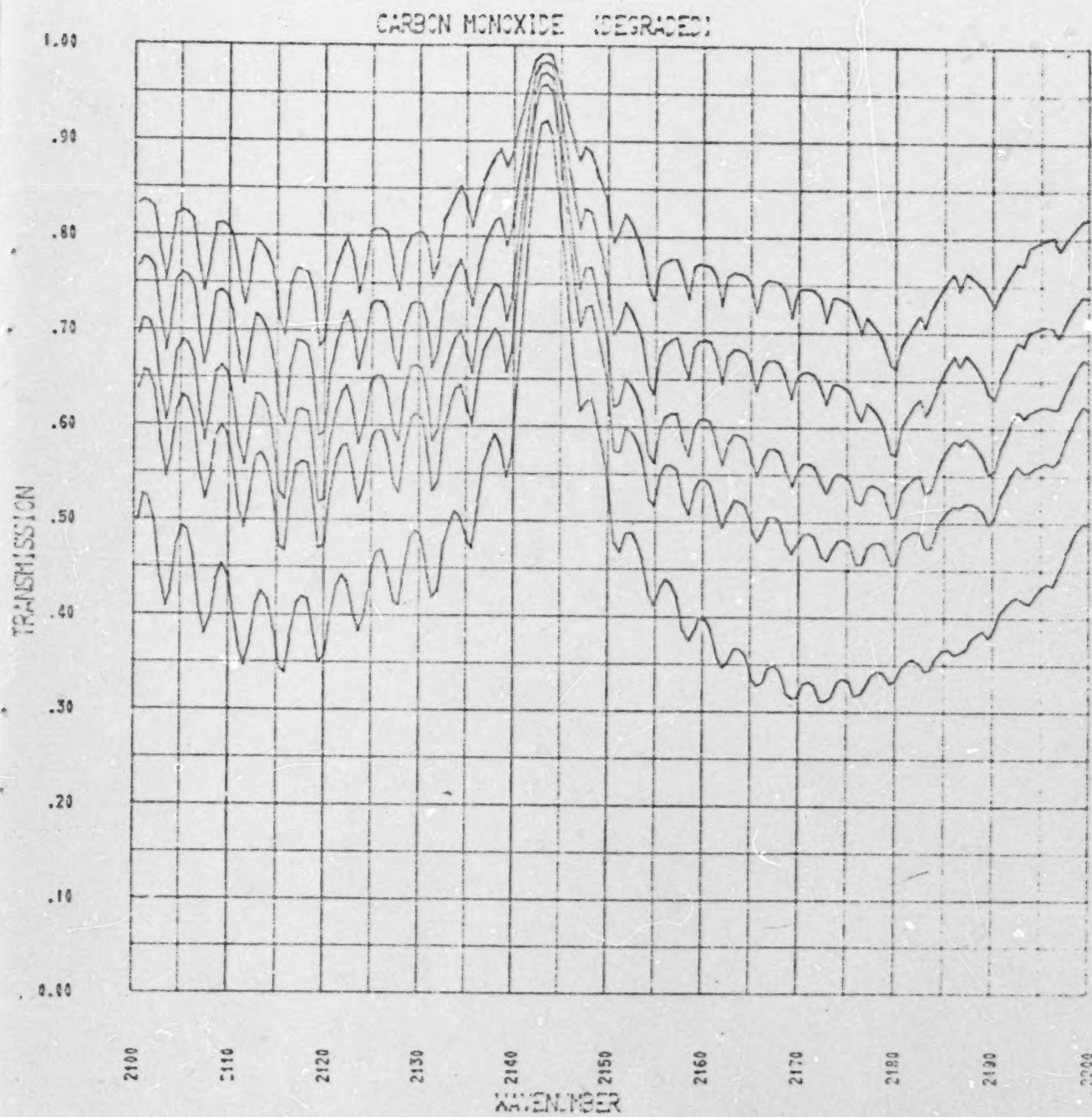
HAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1329.2	0.5060585	1329.4	0.4942770
1329.8	0.4837678	1330.0	0.4827823
1330.4	0.4636048	1330.6	0.4474180
1331.0	0.4288670	1331.2	0.4284586
1331.6	0.4221584	1331.8	0.4115482
1332.2	0.3853964	1332.4	0.3753281
1332.8	0.3690240	1333.0	0.3681554
1333.4	0.3556561	1333.6	0.3451582
1334.0	0.3248471	1334.2	0.3208435
1334.6	0.3222630	1334.8	0.3170383
1335.2	0.2956836	1335.4	0.2850848
1335.8	0.2695812	1336.0	0.2660989
1336.4	0.2582985	1336.6	0.2487047
1337.0	0.2315182	1337.2	0.2285789
1337.6	0.2263890	1337.8	0.2249149
1338.2	0.2078272	1338.4	0.1944007
1338.8	0.1821019	1339.0	0.1853474
1339.4	0.1866891	1339.6	0.1783473
1340.0	0.1573543	1340.2	0.1539489
1340.6	0.1585286	1340.8	0.1573123
1341.2	0.1428887	1341.4	0.1368168
1341.8	0.1361175	1342.0	0.1355904
1342.4	0.1281409	1342.6	0.1223225
1343.0	0.1102952	1343.2	0.1079554
1343.6	0.1125286	1343.8	0.1125000
1344.2	0.1003560	1344.4	0.0941172
1344.8	0.0961408	1345.0	0.1023816
1345.4	0.1052505	1345.6	0.1005260
1346.0	0.0970889	1346.2	0.1009038
1346.6	0.1065652	1346.8	0.1041953
1347.2	0.0987987	1347.4	0.1016100
1347.8	0.1086505	1348.0	0.1071417
1348.4	0.0991166	1348.6	0.0966002
1349.0	0.1012669	1349.2	0.1062629
1349.6	0.1054193	1349.8	0.1006503
1350.2	0.0968184	1350.4	0.0984200
1350.8	0.1054818	1351.0	0.1078941
1351.4	0.1062112	1351.6	0.1066111
1352.0	0.1157222	1352.2	0.1192520
1352.6	0.1198526	1352.8	0.1217151
1353.2	0.1327371	1353.4	0.1370702
1353.8	0.1394050	1354.0	0.1402603
1354.4	0.1432455	1354.6	0.1458956
1355.0	0.1502439	1355.2	0.1494714
1355.6	0.1431051	1355.8	0.1407019
1356.2	0.1395140	1356.4	0.1381865
1356.8	0.1303561	1357.0	0.1256961
1357.4	0.1214916	1357.6	0.1197681
1358.0	0.1137199	1358.2	0.1116189
1358.6	0.1085906	1358.8	0.1052022

TRANSMISSION SPECTRUM FOR SULPHUR DIOXIDE AT 10 TORR

WAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1359.2	0.0926113	1359.4	0.0840119
1359.8	0.0652651	1360.0	0.0577132
1360.4	0.0444780	1360.6	0.0378583
1361.0	0.0297049	1361.2	0.0295466
1361.6	0.0475621	1361.8	0.0781790
1362.2	0.2067500	1362.4	0.2979764
1362.8	0.4748177	1363.0	0.5399328
1363.4	0.6083927	1363.6	0.6156924
1364.0	0.5962220	1364.2	0.5762642
1364.6	0.5299740	1364.8	0.5067082
1365.2	0.4602927	1365.4	0.4369466
1365.8	0.3917812	1366.0	0.3701174
1366.4	0.3250446	1366.6	0.3018246
1367.0	0.2570343	1367.2	0.2360478
1367.6	0.2022404	1367.8	0.1879446
1368.2	0.1580104	1368.4	0.1441544
1368.8	0.1228846	1369.0	0.1145688
1369.4	0.0984205	1369.6	0.0926059
1370.0	0.0880374	1370.2	0.0852525
1370.6	0.0757696	1370.8	0.0713884
1371.2	0.0653888	1371.4	0.0637575
1371.8	0.0599403	1372.0	0.0572741
1372.4	0.0563273	1372.6	0.0585174
1373.0	0.0580362	1373.2	0.0554147
1373.6	0.0552215	1373.8	0.0563714
1374.2	0.0540660	1374.4	0.0527834
1374.8	0.0565480	1375.0	0.0591657
1375.4	0.0603563	1375.6	0.0602170
1376.0	0.0606450	1376.2	0.0602135
1376.6	0.0586554	1376.8	0.0597669
1377.2	0.0656421	1377.4	0.0672822
1377.8	0.0678377	1378.0	0.0691854
1378.4	0.0735816	1378.6	0.0762831
1379.0	0.0839026	1379.2	0.0886009
1379.6	0.0977839	1379.8	0.1020410
1380.2	0.1127426	1380.4	0.1185045
1380.8	0.1259191	1381.0	0.1275601
1381.4	0.1343553	1381.6	0.1417301
1382.0	0.1562327	1382.2	0.1605204
1382.6	0.1717233	1382.8	0.1821284
1383.2	0.2033687	1383.4	0.2092269
1383.8	0.2202155	1384.0	0.2292144
1384.4	0.2467211	1384.6	0.2551813
1385.0	0.2794125	1385.2	0.2929132
1385.6	0.3161187	1385.8	0.3276422
1386.2	0.3521399	1386.4	0.3644588
1386.8	0.3901488	1387.0	0.4020574
1387.4	0.4240741	1387.6	0.4383178
1388.0	0.4749134	1388.2	0.4929870
1388.6	0.5220303	1388.8	0.5320723

TRANSMISSION SPECTRUM FOR SULPHUR DIOXIDE AT 10 TORR

WAVE NUMBER	TRANSMISSION	WAVE NUMBER	TRANSMISSION
1389.2	0.5472171	1389.4	0.5570355
1389.8	0.5842963	1390.0	0.5991194
1390.4	0.6247007	1390.6	0.6356236
1391.0	0.6599099	1391.2	0.6736141
1391.6	0.7009648	1391.8	0.7142709
1392.2	0.7367386	1392.4	0.7463814
1392.8	0.7691489	1393.0	0.7815316
1393.4	0.8006815	1393.6	0.8056305
1394.0	0.8086086	1394.2	0.8099959
1394.6	0.8261948	1394.8	0.8450275
1395.2	0.8915886	1395.4	0.9088072
1395.8	0.9170334	1396.0	0.9118286
1396.4	0.9117697	1396.6	0.9207032
1397.0	0.9346673	1397.2	0.9346793
1397.6	0.9316313	1397.8	0.9337425
1398.2	0.9462791	1398.4	0.9511865
1398.8	0.9473226	1399.0	0.9435365
1399.4	0.9546682	1399.6	0.9712836
1400.0	1.0021460	1400.2	1.0054640
1400.6	0.9915445	1400.8	0.9833780
1401.2	0.9759597	1401.4	0.9752710
1401.8	0.9756918	1402.0	0.9767488
1402.4	0.9781884	1402.6	0.9782556
1403.0	0.9799061	1403.2	0.9810226
1403.6	0.9829075	1403.8	0.9841697
1404.2	0.9861268	1404.4	0.9869444
1404.8	0.9866947	1405.0	0.9855019
1405.4	0.9909227	1405.6	0.9972408
1406.0	1.0015010	1406.2	0.9992702
1406.6	0.9941501	1406.8	0.9915976
1407.2	0.9882850	1407.4	0.9876922
1407.8	0.9861643	1408.0	0.9852003
1408.4	0.9846563	1408.6	0.9858135
1409.0	0.9883092	1409.2	0.9882483



NOT REPRODUCIBLE

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***** CARBON MONOXIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM²)

WAVE NUMBER	5.38E18	1.08E19	1.88E19
2090.00	0.826	0.755	0.690
2090.60	0.796	0.721	0.656
2091.20	0.827	0.759	0.696
2091.80	0.862	0.802	0.742
2092.40	0.863	0.807	0.753
2093.00	0.860	0.804	0.749
2093.60	0.852	0.792	0.731
2094.20	0.813	0.745	0.680
2094.80	0.780	0.706	0.640
2095.40	0.811	0.741	0.674
2096.00	0.848	0.786	0.722
2096.60	0.851	0.794	0.736
2097.20	0.848	0.791	0.732
2097.80	0.840	0.779	0.714
2098.40	0.800	0.731	0.662
2099.00	0.763	0.689	0.619
2099.60	0.794	0.721	0.647
2100.20	0.833	0.766	0.696
2100.80	0.838	0.777	0.712
2101.40	0.836	0.775	0.710
2102.00	0.829	0.764	0.693
2102.60	0.789	0.718	0.644
2103.20	0.752	0.678	0.604
2103.80	0.784	0.710	0.633
2104.40	0.823	0.753	0.677
2105.00	0.826	0.761	0.690
2105.60	0.824	0.758	0.686
2106.20	0.816	0.746	0.667
2106.80	0.775	0.698	0.616
2107.40	0.741	0.664	0.584
2108.00	0.776	0.699	0.616
2108.60	0.812	0.738	0.656
2109.20	0.814	0.742	0.663
2109.80	0.810	0.737	0.656
2110.40	0.800	0.720	0.631
2111.00	0.758	0.671	0.581
2111.60	0.728	0.644	0.558
2112.20	0.768	0.687	0.600
2112.80	0.797	0.718	0.633
2113.40	0.791	0.712	0.633
2114.00	0.781	0.699	0.620
2114.60	0.764	0.673	0.590
2115.20	0.712	0.613	0.530
2115.80	0.695	0.601	0.523
2116.40	0.746	0.659	0.580
2117.00	0.767	0.690	0.616
2117.60	0.765	0.689	0.618
2118.20	0.761	0.684	0.614
2118.80	0.737	0.651	0.576
2119.40	0.683	0.589	0.519

NOT REPRODUCIBLE

***** CARBON MONOXIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	5.38E18	1.08E19	1.88E19
2120.00	0.694	0.595	0.523
2120.60	0.748	0.657	0.583
2121.20	0.771	0.689	0.618
2121.80	0.786	0.708	0.635
2122.40	0.798	0.721	0.643
2123.00	0.776	0.699	0.617
2123.60	0.739	0.659	0.580
2124.20	0.769	0.689	0.605
2124.80	0.805	0.727	0.645
2125.40	0.808	0.732	0.654
2126.00	0.808	0.731	0.653
2126.60	0.804	0.721	0.640
2127.20	0.766	0.678	0.597
2127.80	0.742	0.659	0.584
2128.40	0.784	0.707	0.633
2129.00	0.799	0.729	0.662
2129.60	0.803	0.731	0.664
2130.20	0.804	0.728	0.660
2130.80	0.794	0.708	0.632
2131.40	0.756	0.661	0.584
2132.00	0.776	0.680	0.597
2132.60	0.817	0.731	0.652
2133.20	0.831	0.750	0.676
2133.80	0.844	0.766	0.690
2134.40	0.853	0.776	0.701
2135.00	0.833	0.753	0.679
2135.60	0.810	0.727	0.655
2136.20	0.842	0.768	0.702
2136.80	0.859	0.790	0.727
2137.40	0.872	0.803	0.739
2138.00	0.885	0.816	0.750
2138.60	0.892	0.820	0.747
2139.20	0.873	0.790	0.710
2139.80	0.887	0.812	0.735
2140.40	0.912	0.851	0.789
2141.00	0.936	0.891	0.843
2141.60	0.961	0.932	0.899
2142.20	0.985	0.971	0.952
2142.80	0.991	0.983	0.970
2143.40	0.992	0.984	0.972
2144.00	0.990	0.980	0.966
2144.60	0.969	0.949	0.927
2145.20	0.946	0.912	0.879
2145.80	0.923	0.875	0.832
2146.40	0.899	0.839	0.784
2147.00	0.879	0.807	0.745
2147.60	0.894	0.830	0.768
2148.20	0.888	0.825	0.768
2148.80	0.870	0.801	0.742
2149.40	0.851	0.776	0.712

NOT REPRODUCIBLE

***** CARBON MONOXIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	5.38E18	1.08E19	1.88E19
2150.00	0.831	0.748	0.680
2150.60	0.794	0.697	0.621
2151.20	0.807	0.708	0.626
2151.80	0.825	0.732	0.651
2152.40	0.813	0.721	0.644
2153.00	0.800	0.707	0.632
2153.60	0.785	0.691	0.616
2154.20	0.747	0.645	0.571
2154.80	0.734	0.634	0.562
2155.40	0.770	0.676	0.600
2156.00	0.775	0.686	0.612
2156.60	0.777	0.691	0.615
2157.20	0.777	0.694	0.614
2157.80	0.761	0.672	0.586
2158.40	0.735	0.649	0.569
2159.00	0.768	0.684	0.598
2159.60	0.772	0.691	0.609
2160.20	0.771	0.692	0.609
2160.80	0.769	0.690	0.605
2161.40	0.758	0.673	0.581
2162.00	0.728	0.646	0.560
2162.60	0.759	0.675	0.582
2163.20	0.763	0.682	0.593
2163.80	0.762	0.682	0.593
2164.40	0.760	0.679	0.588
2165.00	0.751	0.664	0.568
2165.60	0.721	0.638	0.549
2166.20	0.751	0.664	0.567
2166.80	0.755	0.671	0.578
2167.40	0.755	0.671	0.578
2168.00	0.753	0.668	0.574
2168.60	0.745	0.655	0.555
2169.20	0.715	0.631	0.538
2169.80	0.744	0.654	0.553
2170.40	0.747	0.659	0.563
2171.00	0.746	0.659	0.563
2171.60	0.745	0.656	0.559
2172.20	0.737	0.643	0.542
2172.80	0.711	0.624	0.531
2173.40	0.738	0.646	0.547
2174.00	0.737	0.647	0.552
2174.60	0.735	0.644	0.550
2175.20	0.731	0.638	0.545
2175.80	0.719	0.620	0.524
2176.40	0.698	0.608	0.520
2177.00	0.718	0.626	0.538
2177.60	0.710	0.621	0.540
2178.20	0.701	0.612	0.537
2178.80	0.690	0.602	0.531
2179.40	0.668	0.574	0.506

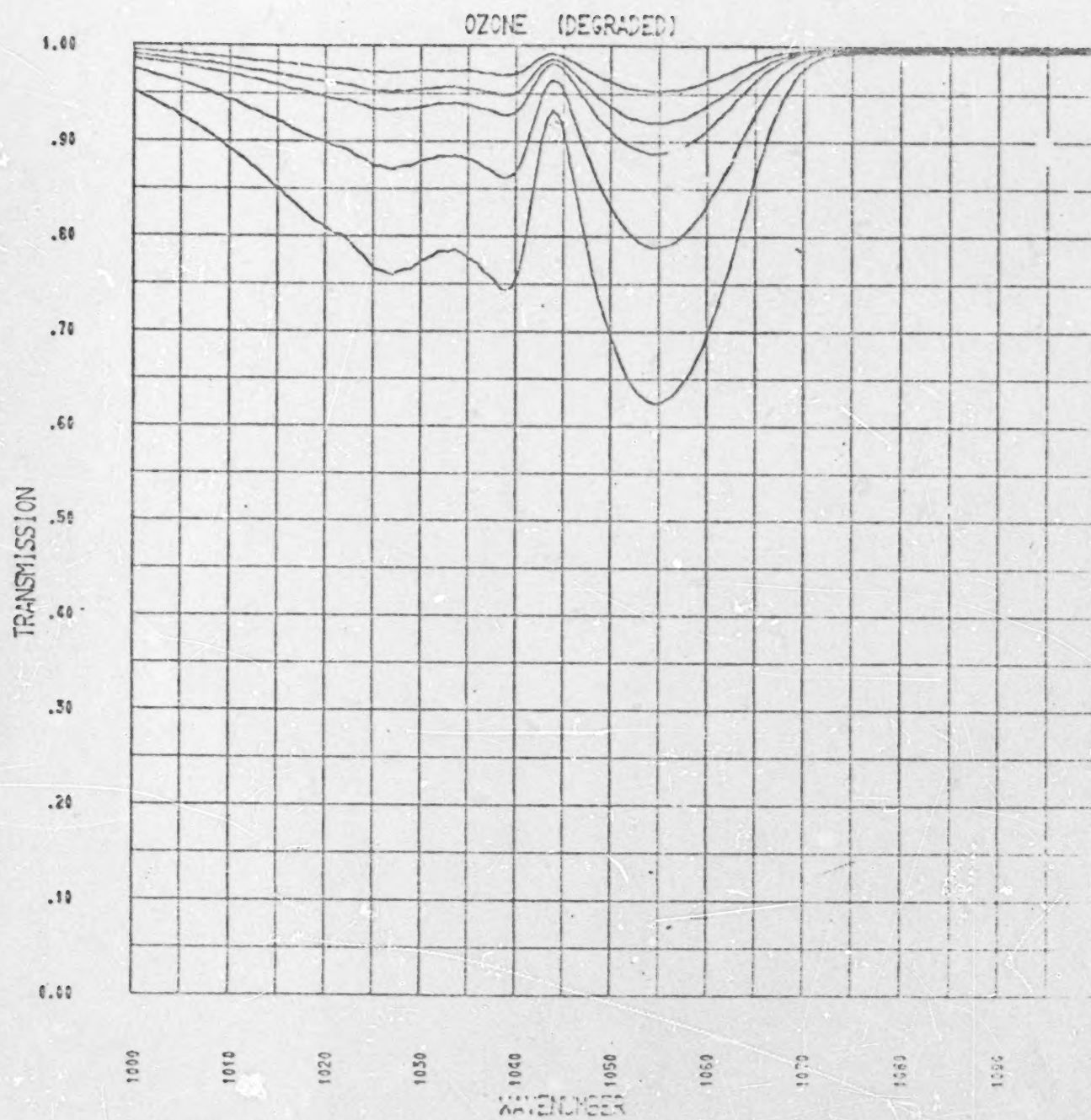
NOT REPRODUCIBLE

***** CARBON MONOXIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

HAVE NUMBER	5.38E18	1.08E19	1.88E19
2180.00	0.662	0.573	0.507
2180.60	0.686	0.601	0.534
2181.20	0.698	0.613	0.542
2181.80	0.709	0.623	0.548
2182.40	0.719	0.631	0.550
2183.00	0.706	0.613	0.532
2183.60	0.724	0.624	0.535
2184.20	0.737	0.643	0.556
2184.80	0.747	0.656	0.570
2185.40	0.756	0.668	0.581
2186.00	0.764	0.677	0.588
2186.60	0.746	0.666	0.584
2187.20	0.764	0.678	0.590
2187.80	0.760	0.671	0.585
2188.40	0.755	0.662	0.578
2189.00	0.750	0.652	0.569
2189.60	0.741	0.637	0.552
2190.20	0.728	0.631	0.555
2190.80	0.743	0.652	0.579
2191.40	0.754	0.667	0.594
2192.00	0.765	0.680	0.607
2192.60	0.775	0.693	0.619
2193.20	0.772	0.687	0.611
2193.80	0.791	0.702	0.618
2194.40	0.795	0.705	0.621
2195.00	0.798	0.707	0.623
2195.60	0.800	0.708	0.624
2196.20	0.802	0.707	0.621
2196.80	0.788	0.697	0.621
2197.40	0.798	0.710	0.638
2198.00	0.805	0.721	0.650
2198.60	0.813	0.731	0.662
2199.20	0.820	0.740	0.673
2199.80	0.821	0.739	0.670
2200.40	0.833	0.749	0.675
2201.00	0.832	0.744	0.666
2201.60	0.832	0.739	0.656
2202.20	0.832	0.733	0.647
2202.80	0.830	0.726	0.635
2203.40	0.828	0.725	0.637
2204.00	0.839	0.743	0.660
2204.60	0.850	0.761	0.682
2205.20	0.861	0.778	0.705
2205.80	0.872	0.795	0.726
2206.40	0.872	0.798	0.731
2207.00	0.878	0.805	0.739
2207.60	0.883	0.812	0.746
2208.20	0.888	0.818	0.753
2208.80	0.893	0.825	0.760
2209.40	0.897	0.829	0.763

NOT REPRODUCIBLE



NOT REPRODUCIBLE

A-17

A-17

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	1.08E17	1.88E17	2.69E17
996.40	0.997	0.994	0.992
997.00	0.996	0.994	0.991
997.60	0.996	0.994	0.991
998.20	0.996	0.993	0.990
998.80	0.996	0.993	0.990
999.40	0.996	0.992	0.989
1000.00	0.995	0.992	0.988
1000.60	0.995	0.991	0.987
1001.20	0.995	0.991	0.987
1001.80	0.994	0.990	0.986
1002.40	0.994	0.990	0.985
1003.00	0.994	0.989	0.984
1003.60	0.993	0.988	0.983
1004.20	0.993	0.988	0.983
1004.80	0.993	0.987	0.982
1005.40	0.992	0.986	0.981
1006.00	0.992	0.986	0.980
1006.60	0.991	0.985	0.979
1007.20	0.991	0.984	0.977
1007.80	0.991	0.984	0.977
1008.40	0.990	0.983	0.975
1009.00	0.990	0.982	0.974
1009.60	0.989	0.981	0.973
1010.20	0.989	0.980	0.972
1010.80	0.988	0.979	0.971
1011.40	0.988	0.978	0.969
1012.00	0.987	0.977	0.968
1012.60	0.986	0.976	0.967
1013.20	0.986	0.975	0.965
1013.80	0.985	0.974	0.963
1014.40	0.984	0.973	0.962
1015.00	0.984	0.972	0.961
1015.60	0.983	0.971	0.959
1016.20	0.983	0.970	0.957
1016.80	0.982	0.969	0.956
1017.40	0.982	0.968	0.955
1018.00	0.981	0.967	0.953
1018.60	0.980	0.966	0.951
1019.20	0.980	0.965	0.950
1019.80	0.979	0.964	0.949
1020.40	0.979	0.963	0.948
1021.00	0.978	0.963	0.947
1021.60	0.978	0.962	0.946
1022.20	0.978	0.961	0.945
1022.80	0.977	0.960	0.943
1023.40	0.976	0.959	0.941
1024.00	0.975	0.957	0.940
1024.60	0.974	0.955	0.937
1025.20	0.974	0.954	0.936
1025.80	0.974	0.954	0.935

NOT REPRODUCIBLE

***** OZONE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	1.08E17	1.88E17	2.69E17
1026.40	0.973	0.954	0.934
1027.00	0.973	0.953	0.934
1027.60	0.973	0.954	0.935
1028.20	0.974	0.954	0.935
1028.80	0.974	0.954	0.936
1029.40	0.974	0.955	0.937
1030.00	0.975	0.956	0.938
1030.60	0.975	0.957	0.939
1031.20	0.975	0.957	0.940
1031.80	0.976	0.958	0.941
1032.40	0.976	0.959	0.941
1033.00	0.976	0.959	0.941
1033.60	0.976	0.959	0.941
1034.20	0.976	0.958	0.942
1034.80	0.975	0.957	0.941
1035.40	0.975	0.957	0.940
1036.00	0.974	0.956	0.939
1036.60	0.973	0.954	0.937
1037.20	0.973	0.953	0.935
1037.80	0.972	0.952	0.934
1038.40	0.971	0.950	0.932
1039.00	0.971	0.950	0.930
1039.60	0.971	0.950	0.929
1040.20	0.973	0.953	0.930
1040.80	0.976	0.959	0.934
1041.40	0.980	0.966	0.941
1042.00	0.985	0.974	0.952
1042.60	0.989	0.981	0.963
1043.20	0.992	0.986	0.973
1043.80	0.993	0.988	0.980
1044.40	0.992	0.987	0.983
1045.00	0.990	0.983	0.981
1045.60	0.987	0.978	0.976
1046.20	0.984	0.972	0.969
1046.80	0.980	0.966	0.960
1047.40	0.977	0.960	0.951
1048.00	0.973	0.954	0.943
1048.60	0.970	0.948	0.934
1049.20	0.967	0.943	0.927
1049.80	0.965	0.939	0.920
1050.40	0.962	0.935	0.914
1051.00	0.960	0.931	0.908
1051.60	0.958	0.928	0.903
1052.20	0.957	0.926	0.899
1052.80	0.956	0.924	0.895
1053.40	0.955	0.922	0.893
1054.00	0.954	0.921	0.891
1054.60	0.954	0.921	0.889
1055.20	0.954	0.921	0.889
1055.80	0.954	0.921	0.889

NOT REPRODUCIBLE

***** OZONE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	1.08E17	1.88E17	2.69E17
1056.40	0.955	0.923	0.891
1057.00	0.956	0.924	0.894
1057.60	0.957	0.926	0.897
1058.20	0.959	0.929	0.900
1058.80	0.960	0.932	0.904
1059.40	0.962	0.935	0.909
1060.00	0.964	0.939	0.913
1060.60	0.967	0.943	0.919
1061.20	0.969	0.947	0.925
1061.80	0.972	0.951	0.931
1062.40	0.974	0.955	0.937
1063.00	0.977	0.960	0.944
1063.60	0.980	0.965	0.950
1064.20	0.982	0.969	0.957
1064.80	0.985	0.974	0.963
1065.40	0.987	0.978	0.969
1066.00	0.989	0.981	0.974
1066.60	0.991	0.985	0.978
1067.20	0.993	0.988	0.982
1067.80	0.994	0.990	0.986
1068.40	0.995	0.992	0.989
1069.00	0.996	0.994	0.991
1069.60	0.997	0.995	0.993
1070.20	0.998	0.996	0.995
1070.80	0.998	0.997	0.996
1071.40	0.999	0.998	0.997
1072.00	0.999	0.998	0.998
1072.60	0.999	0.999	0.998
1073.20	0.999	0.999	0.998
1073.80	0.999	0.999	0.998
1074.40	0.999	0.999	0.998
1075.00	0.999	0.999	0.998
1075.60	0.999	0.999	0.999
1076.20	1.000	0.999	0.999
1076.80	1.000	0.999	0.999
1077.40	1.000	0.999	0.999
1078.00	1.000	0.999	0.999
1078.60	1.000	0.999	0.999
1079.20	1.000	0.999	0.999
1079.80	1.000	0.999	0.999
1080.40	1.000	0.999	0.999
1081.00	0.999	0.999	0.999
1081.60	0.999	0.999	0.999
1082.20	1.000	0.999	0.999
1082.80	1.000	0.999	0.999
1083.40	1.000	0.999	0.999
1084.00	1.000	0.999	0.999
1084.60	1.000	0.999	0.999
1085.20	1.000	0.999	0.999
1085.80	1.000	0.999	0.999

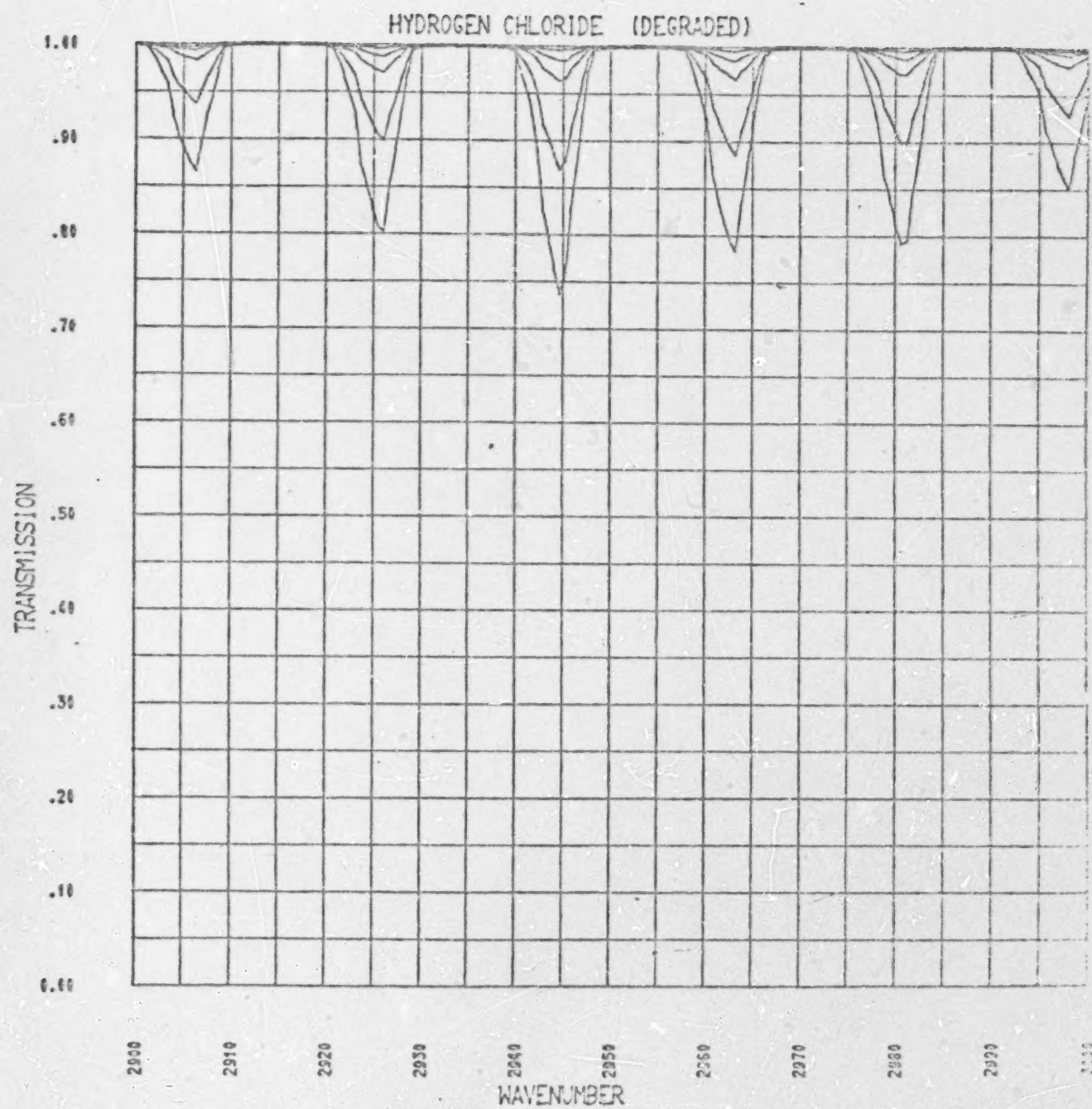
NOT REPRODUCIBLE

***** OZONE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	1.08E17	1.88E17	2.69E17
1086.40	1.000	0.999	0.999
1087.00	1.000	0.999	0.999
1087.60	1.000	0.999	0.999
1088.20	1.000	0.999	0.999
1088.80	1.000	0.999	0.999
1089.40	1.000	0.999	0.999
1090.00	1.000	0.999	0.999
1090.60	1.000	0.999	0.999
1091.20	1.000	0.999	0.999
1091.80	1.000	0.999	0.999
1092.40	1.000	0.999	0.999
1093.00	1.000	0.999	0.999
1093.60	1.000	0.999	0.999
1094.20	1.000	0.999	0.999
1094.80	1.000	0.999	0.999
1095.40	1.000	0.999	0.999
1096.00	1.000	0.999	0.999
1096.60	1.000	0.999	0.999
1097.20	1.000	0.999	0.999
1097.80	1.000	0.999	0.999
1098.40	1.000	0.999	0.999
1099.00	1.000	0.999	0.999
1099.60	1.000	0.999	0.999
1100.20	1.000	0.999	0.999
1100.80	1.000	0.999	0.999
1101.40	1.000	0.999	0.999
1102.00	1.000	0.999	0.999
1102.60	1.000	0.999	0.999
1103.20	1.000	0.999	0.999
1103.80	1.000	0.999	0.999
1104.40	1.000	0.999	0.999
1105.00	1.000	1.000	0.999
1105.60	1.000	1.000	0.999
1106.20	1.000	1.000	0.999
1106.80	1.000	1.000	0.999
1107.40	1.000	1.000	0.999
1108.00	1.000	1.000	0.999
1108.60	1.000	1.000	0.999
1109.20	1.000	1.000	0.999
1109.80	1.000	1.000	0.999
1110.40	1.000	1.000	0.999
1111.00	1.000	0.999	0.999
1111.60	1.000	0.999	0.999
1112.20	1.000	0.999	0.999
1112.80	1.000	0.999	0.999
1113.40	1.000	0.999	0.999
1114.00	1.000	0.999	0.999
1114.60	1.000	0.999	0.999
1115.20	1.000	0.999	0.999
1115.80	1.000	0.999	0.999

NOT REPRODUCIBLE



NOT REPRODUCIBLE

A-22

A-22

***** HYDROGEN CHLORIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM²)

WAVE NUMBER	2.69E16	1.08E17	2.69E17
2880.40	1.000	1.000	1.000
2881.00	1.000	1.000	1.000
2881.60	1.000	1.000	1.000
2882.20	1.000	1.000	1.000
2882.80	1.000	1.000	1.000
2883.40	1.000	1.000	1.000
2884.00	1.000	1.000	1.000
2884.60	1.000	1.000	1.000
2885.20	1.000	1.000	1.000
2885.80	1.000	1.000	1.000
2886.40	1.000	1.000	1.000
2887.00	1.000	1.000	1.000
2887.60	1.000	1.000	1.000
2888.20	1.000	1.000	1.000
2888.80	1.000	1.000	1.000
2889.40	1.000	1.000	1.000
2890.00	1.000	1.000	1.000
2890.60	1.000	1.000	1.000
2891.20	1.000	1.000	1.000
2891.80	1.000	1.000	1.000
2892.40	1.000	1.000	1.000
2893.00	1.000	1.000	1.000
2893.60	1.000	1.000	1.000
2894.20	1.000	1.000	1.000
2894.80	1.000	1.000	1.000
2895.40	1.000	1.000	1.000
2896.00	1.000	1.000	1.000
2896.60	1.000	1.000	1.000
2897.20	1.000	1.000	1.000
2897.80	1.000	1.000	1.000
2898.40	1.000	1.000	1.000
2899.00	1.000	1.000	1.000
2899.60	1.000	1.000	1.000
2900.20	1.000	1.000	1.000
2900.80	1.000	1.000	1.000
2901.40	1.000	1.000	1.000
2902.00	1.000	0.999	0.999
2902.60	1.000	0.999	0.998
2903.20	1.000	0.998	0.997
2903.80	0.999	0.997	0.995
2904.40	0.999	0.995	0.992
2905.00	0.999	0.995	0.989
2905.60	0.998	0.994	0.987
2906.20	0.998	0.993	0.985
2906.80	0.999	0.995	0.983
2907.40	0.999	0.996	0.987
2908.00	0.999	0.997	0.990
2908.60	1.000	0.999	0.993
2909.20	1.000	1.000	0.997
2909.80	1.000	1.000	1.000

NOT REPRODUCIBLE

***** HYDROGEN CHLORIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM²)

WAVE NUMBER	2.69E16	1.08E17	2.69E17
2910.40	1.000	1.000	1.000
2911.00	1.000	1.000	1.000
2911.60	1.000	1.000	1.000
2912.20	1.000	1.000	1.000
2912.80	1.000	1.000	1.000
2913.40	1.000	1.000	1.000
2914.00	1.000	1.000	1.000
2914.60	1.000	1.000	1.000
2915.20	1.000	1.000	1.000
2915.80	1.000	1.000	1.000
2916.40	1.000	1.000	1.000
2917.00	1.000	1.000	1.000
2917.60	1.000	1.000	1.000
2918.20	1.000	1.000	1.000
2918.80	1.000	1.000	1.000
2919.40	1.000	1.000	1.000
2920.00	1.000	1.000	1.000
2920.60	1.000	1.000	1.000
2921.20	1.000	0.999	0.998
2921.80	1.000	0.998	0.996
2922.40	0.999	0.998	0.994
2923.00	0.999	0.997	0.991
2923.60	0.998	0.994	0.988
2924.20	0.998	0.992	0.986
2924.80	0.998	0.990	0.977
2925.40	0.997	0.989	0.973
2926.00	0.997	0.988	0.971
2926.60	0.998	0.991	0.978
2927.20	0.998	0.993	0.984
2927.80	0.999	0.996	0.989
2928.40	0.999	0.998	0.995
2929.00	1.000	1.000	0.999
2929.60	1.000	1.000	1.000
2930.20	1.000	1.000	1.000
2930.80	1.000	1.000	1.000
2931.40	1.000	1.000	1.000
2932.00	1.000	1.000	1.000
2932.60	1.000	1.000	1.000
2933.20	1.000	1.000	1.000
2933.80	1.000	1.000	1.000
2934.40	1.000	1.000	1.000
2935.00	1.000	1.000	1.000
2935.60	1.000	1.000	1.000
2936.20	1.000	1.000	1.000
2936.80	1.000	1.000	1.000
2937.40	1.000	1.000	1.000
2938.00	1.000	1.000	1.000
2938.60	1.000	1.000	1.000
2939.20	1.000	1.000	1.000
2939.80	1.000	1.000	0.999

NOT REPRODUCIBLE

A-24

A-24

***** HYDROGEN CHLORIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	2.69E16	1.08E17	2.69E17
2940.40	1.000	0.999	0.997
2941.00	0.999	0.998	0.995
2941.60	0.999	0.997	0.992
2942.20	0.999	0.994	0.986
2942.80	0.998	0.991	0.977
2943.40	0.997	0.989	0.972
2944.00	0.997	0.987	0.968
2944.60	0.996	0.985	0.963
2945.20	0.997	0.986	0.966
2945.80	0.997	0.990	0.975
2946.40	0.998	0.993	0.982
2947.00	0.999	0.996	0.989
2947.60	1.000	0.999	0.996
2948.20	1.000	1.000	0.999
2948.80	1.000	1.000	1.000
2949.40	1.000	1.000	1.000
2950.00	1.000	1.000	1.000
2950.60	1.000	1.000	1.000
2951.20	1.000	1.000	1.000
2951.80	1.000	1.000	1.000
2952.40	1.000	1.000	1.000
2953.00	1.000	1.000	1.000
2953.60	1.000	1.000	1.000
2954.20	1.000	1.000	1.000
2954.80	1.000	1.000	1.000
2955.40	1.000	1.000	1.000
2956.00	1.000	1.000	1.000
2956.60	1.000	1.000	1.000
2957.20	1.000	1.000	1.000
2957.80	1.000	1.000	1.000
2958.40	1.000	0.999	0.998
2959.00	1.000	0.998	0.996
2959.60	0.999	0.997	0.993
2960.20	0.999	0.996	0.991
2960.80	0.998	0.993	0.983
2961.40	0.998	0.991	0.978
2962.00	0.997	0.989	0.974
2962.60	0.997	0.987	0.970
2963.20	0.996	0.986	0.966
2963.80	0.997	0.989	0.974
2964.40	0.998	0.992	0.980
2965.00	0.999	0.994	0.987
2965.60	0.999	0.997	0.993
2966.20	1.000	1.000	0.999
2966.80	1.000	1.000	1.000
2967.40	1.000	1.000	1.000
2968.00	1.000	1.000	1.000
2968.60	1.000	1.000	1.000
2969.20	1.000	1.000	1.000
2969.80	1.000	1.000	1.000

NOT REPRODUCIBLE

***** HYDROGEN CHLORIDE *****

TRANSMISSION SPECTRA FOR 3 CONCENTRATIONS
(MOL/CM 2)

WAVE NUMBER	2.69E16	1.08E17	2.69E17
2970.40	1.000	1.000	1.000
2971.00	1.000	1.000	1.000
2971.60	1.000	1.000	1.000
2972.20	1.000	1.000	1.000
2972.80	1.000	1.000	1.000
2973.40	1.000	1.000	1.000
2974.00	1.000	1.000	1.000
2974.60	1.000	1.000	1.000
2975.20	1.000	1.000	1.000
2975.80	1.000	1.000	1.000
2976.40	1.000	0.999	0.998
2977.00	1.000	0.998	0.996
2977.60	0.999	0.998	0.994
2978.20	0.999	0.996	0.991
2978.80	0.998	0.993	0.984
2979.40	0.998	0.992	0.980
2980.00	0.998	0.990	0.976
2980.60	0.997	0.989	0.972
2981.20	0.997	0.988	0.972
2981.80	0.998	0.991	0.979
2982.40	0.998	0.994	0.984
2983.00	0.999	0.996	0.990
2983.60	1.000	0.998	0.996
2984.20	1.000	1.000	1.000
2984.80	1.000	1.000	1.000
2985.40	1.000	1.000	1.000
2986.00	1.000	1.000	1.000
2986.60	1.000	1.000	1.000
2987.20	1.000	1.000	1.000
2987.80	1.000	1.000	1.000
2988.40	1.000	1.000	1.000
2989.00	1.000	1.000	1.000
2989.60	1.000	1.000	1.000
2990.20	1.000	1.000	1.000
2990.80	1.000	1.000	1.000
2991.40	1.000	1.000	1.000
2992.00	1.000	1.000	1.000
2992.60	1.000	1.000	1.000
2993.20	1.000	0.999	0.999
2993.80	1.000	0.999	0.997
2994.40	1.000	0.998	0.996
2995.00	0.999	0.998	0.994
2995.60	0.999	0.996	0.990
2996.20	0.999	0.995	0.987
2996.80	0.998	0.994	0.984
2997.40	0.998	0.993	0.982
2998.00	0.998	0.992	0.980
2998.60	0.998	0.994	0.984
2999.20	0.999	0.995	0.988
2999.80	0.999	0.997	0.992

NOT REPRODUCIBLE

APPENDIX B

B-1

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2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
PROGRAM NAPCA
  DIMENSION S(5),KX(10),IDGAS(10),W(10),WI(10),WO(10),WIO(10),
1 WIT(10),ERR(160),XTM(160,11)
  DIMENSION TRAN(1000,10),NU(10),NW(10),UR(10,3),WR(10,10),TG(150),
1 U(150),CF(150),TC(150),WM(10),WHR(10),WW(10),IPW(10)
  COMMON TRAN,NG,NU,NW,UR,WR,NT,TG,U,CF,TC,WM,WHR,WW,IPW,RMSTP,RMST,
1 RMSW
  EXTERNAL CALC
1 CALL CONST(S,WM,WHR,WW,IPW,UMIN,UMAX,ZEPO,KX,Q,MK,GLB,CFM,IPRNT,
1 IPLOT)
  IS=1
15 Z=THEOTRN(TRAN,NG,IDGAS,NU,NW,UR,WR)
151 IF(Z)152,2
152 PRINT 1521
1521 FORMAT(1H1,91H*****ERROR IN READING THEORETICAL VALUES OF TR
1 ANSMISSION***EXECUTION TERMINATED****)
  CALL EXIT
2 IPR=IPL=NM=0
  RMSTP=1.E100
  CALL READALL(NG,S,UMIN,UMAX,WM,WHR,WW,IPW,ZEPO,KX,Q,GLB,MK,CFM,
1 IPRNT,IPLOT,W,WI,WO,WIO,NT,TG,U,CF)
  ZEP=ZEPO
  INC=0
21 CALL PRINT1(Q,GLB,CFM,MK,IPRNT,IPLOT,UMIN,UMAX,ZEP,KX,NG,IDGAS,W,
1 WI,WM,WHR,WW,IPW,NT,TG,U,CF)
22 IF(KX(1))221,221,3
221 INC=1
  KX(1)=XABSF(KX(1))
3 CALL CALC(W,ERR,RMS)
31 DO 319 K=1,NG
319 WIT(K)=WI(K)
35 CALL PRINT2(NM,Q,GLB,MK,ZEP,KX,RMS,RMST,RMSW,NG,IDGAS,WO,W,WI,WM,
1 WHR,WW,IPW,NT,TG,TC,U,CF,ERR)
36 CALL PLOTT(NT,TG,TC,U,NG,W,IDGAS,NM)
38 IF(GLB-RMS)4,5,5
4 CALL MINMYZD(W,WIT,NG,CALC,ERR,NG+NT,ZEP,KX,1.,RMS,XTM)
41 IPR=IPR+1
  IPL=IPL+1
  NM=NM+1
42 IF(IPR-IPRNT)44,43,44
43 IPR=0
  CALL PRINT2(NM,Q,GLB,MK,ZEP,KX,RMS,RMST,RMSW,NG,IDGAS,WO,W,WIT,WM,
1 WHR,WW,IPW,NT,TG,TC,U,CF,ERR)
44 IF(IPL-IPLOT)46,45,46
45 IPL=0
  CALL PLOTT(NT,TG,TC,U,NG,W,IDGAS,NM)
46 KX(4)=XABSF(KX(4))
47 ICXMIZ=CXMIZ(KX,Q,GLB,MK-NM,RMS)
471 GO TO (4711,5,472),ICXMIZ
4711 IF(INC-1) GO TO 4
4712 DO 4719 K=1,NG
  WI(K)=.9*WI(K)
4719 WIT(K)=WI(K)
  GO TO 4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
472 PRINT 4721
4721 FORMAT(1H0,8X,115H***** SINGULAR MATRIX *** COMPUTA
TION HALTED *** NEXT SET OF DATA TO BE READ IN *****
2*)
GO TO 6
5 CALL PRINT3(NG,IDGAS,WO,W,WM,WHR,WW,IPW,NT,TG,TC,U,CF,ERR,RMS,
1 RMST,RMSW)
CALL PLOTT(NT,TG,TC,U,NG,W,IDGAS,-NM)
CALL PLOTD(NT,TG,TC,U,NG,W,IDGAS)
6 DO 609 K=1,NG
609 WI(K)=WIT(K)
GO TO 2
END

```

APPENDIX C

```

C: PROGRAM RAMANDUCC TO CALCULATE RELATIVE RAMAN CROSS SECTION
C: AND DEPOLARIZATION RATIO FOR GASES. FILE /INPUT/ IS LOADED
C: BY PROCESSING PROGRAM /SIG/, AND /INST/ IS LOADED BY HAND.
C: FIRST SUBSCRIPT REFERS TO SAMPLE (1) OR REFERENCE (2), AND
C: SECOND TO ORTHOGONAL (1) OR PARALLEL (2) POLARIZATION.
1 FORMAT(SFOR SAMPLE, A=SE11.5S B=SE11.5//)
2 FORMAT(SFOR REFERENCE, A=SE11.5S B=SE11.5/S RH0=S
1F7.4S (EXPECT .055) S12S ITERATIONS/)
4 FORMAT(SINST VARIABLES ARE S1S S3I3,F4.1S SF4.1S S
12(I5S S)/S S2(I5S S),2F6.4,2F6.1/)
5 FORMAT(4E11.5)
6 FORMAT(I5,3I3,2F4.1,4I5,2F6.4,2F6.1/)
7 FORMAT(SAT S1S CM-1 PUMP, RELATIVE CROSS SECTION IS SF8.4S,S/
2SDEPOLARIZATION RATIO IS SF7.4S,S)
8 FORMAT(SINPUT DATA IS S4(F7.0S, S)S(CTS/SEC)CM-1S/)
9 FORMAT(SPOLARIZATION CORRECTION RATIO IS SF7.4/)
DIMENSION NU(2),DATA(2,2),EFF(2),CTS(2),LMP(2),POLRAT(2),
2A(2),B(2),PRES(2)
OPEN (2,INPUT,/INPUT/)
OPEN (3,INPUT,/INST/)
DO 10 J=1,2
DO 10 I=1,2
10 READ 2,5, DATA(I,J)
READ 3,6, IGNU,SLIT,HT,SCAN,FNC,FNI,(NU(K),K=1,2),(LMP(L),
1L=1,2),(POLRAT(M),M=1,2),(PRES(N),N=1,2)
WRITE 1,3, ((DATA(I,J),I=1,2),J=1,2)
WRITE 1,4, IGNU,SLIT,HT,SCAN,FNC,FNI,(NU(K),K=1,2),(LMP(L),
1L=1,2),(POLRAT(M),M=1,2),(PRES(N),N=1,2)
C: CALCULATE REFERENCE DEPOLARIZATION RATIO AND CORRECT DATA(1,2)
C: FOR SIGNAL LOSS FROM ALIGNMENT CHANGES DUE TO ROTATION OF
C: HALF-WAVE PLATE.
CTS(1)=DATA(2,1); CTS(2)=DATA(2,2)
PRAT=POLRAT(2); INU=NU(2); ILMP=LMP(2)

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NOT REPRODUCIBLE

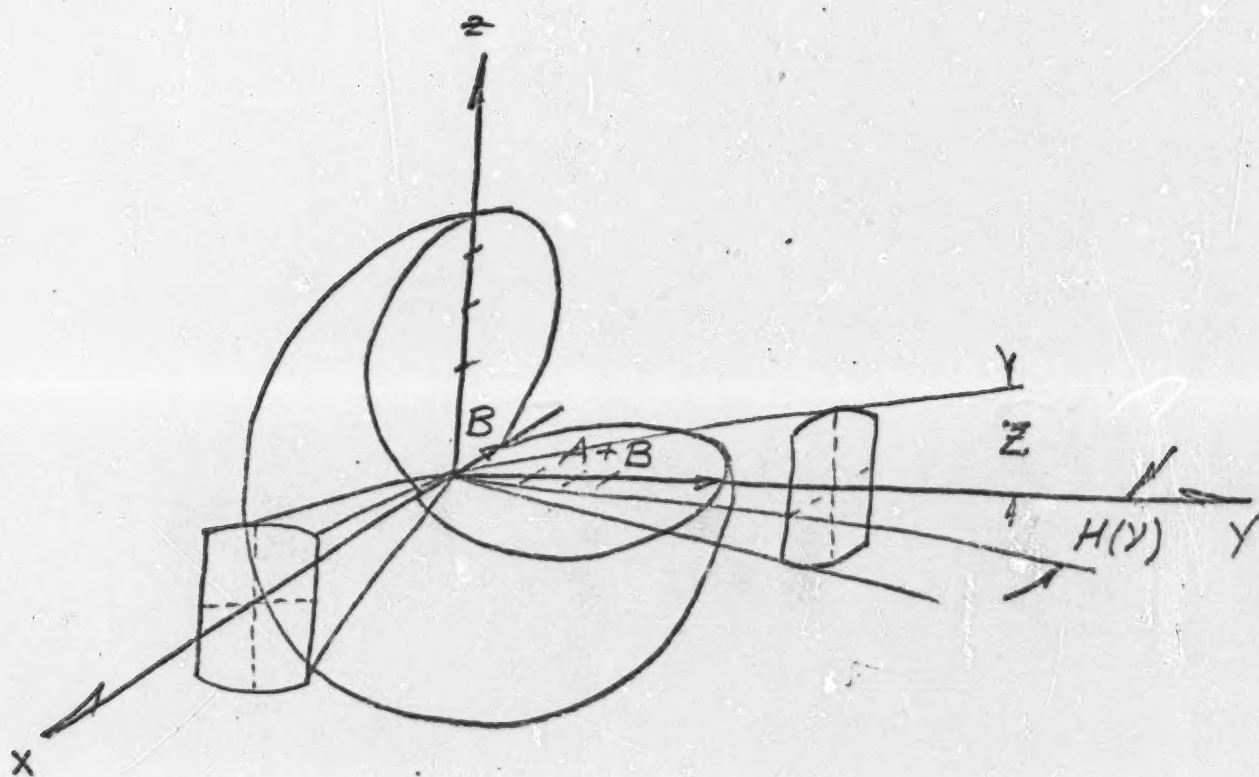
```

03 20 I=1,5
CALL COMPUTE(CTS,INU,SLIT,HT,FNC,FNI,PRAT,ILMP,X,Y,EFF,C,D,E,F)
Z=.0582*X
AVEF=(EFF(1)+EFF(2))/2.
DET=AVEF*(D*E*EFF(1)-C*F*AVEF)
ZZ=(Z*DET+CTS(1)*C*AVEF)/(E*EFF(1))
CTS(2)=ZZ
RAT=CTS(2)/DATA(2,2)
RH3=Y/(X+Y)
IF(ABS(RH3-.055)/.055-.01) 22,22,20
20 CONTINUE
22 WRITE 1,9, RAT
WRITE 1,2, X,Y,RH3,I
A(2)=X; B(2)=Y
DATA(1,2)=RAT*DATA(1,2)
CTS(1)=DATA(1,1); CTS(2)=DATA(1,2)
PRAT=P3LRAT(1); INU=NU(1); ILMP=LMP(1)
CALL COMPUTE(CTS,INU,SLIT,HT,FNC,FNI,PRAT,ILMP,X,Y,EFF,C,D,E,F)
A(1)=X; B(1)=Y
WRITE 1,1, A(1),B(1)
CROSS=((A(1)+B(1))*PRES(2))/((A(2)+B(2))*PRES(1))
P3L=B(1)/(A(1)+B(1))
WRITE 1,7, IGNU,CROSS,P3L
END

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NOT REPRODUCIBLE

GEOCOR

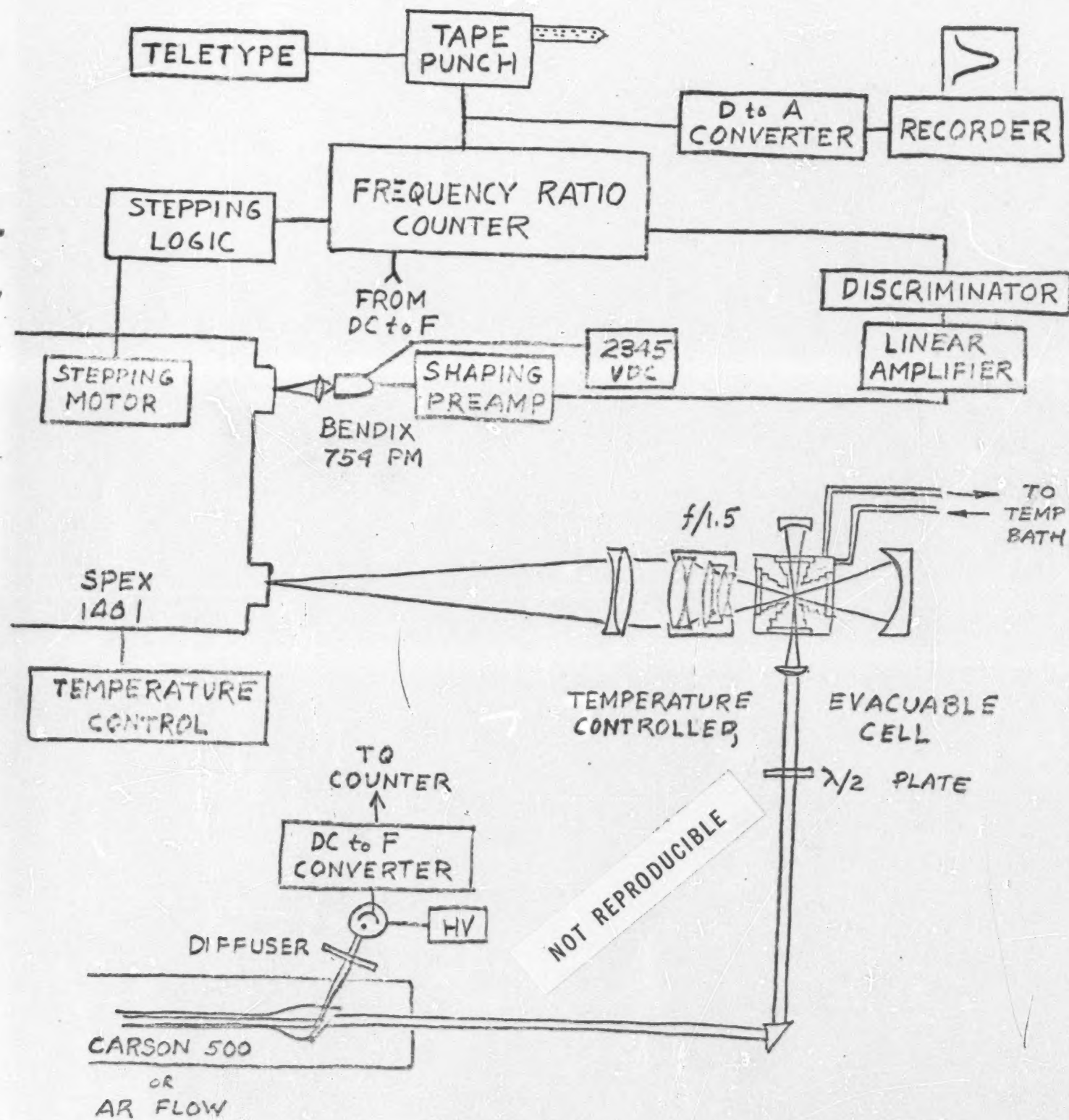


$$I_x = \int_{\Omega_x} (A \sin^2 \varphi + B) d\Omega$$

$$I_y = \int_{\Omega_y} (A \sin^2 \varphi + B) d\Omega$$

⇒ 4 GEOMETRICAL CORRECTION FACTORS

RAMAN SPECTROMETER DEVELOPMENT



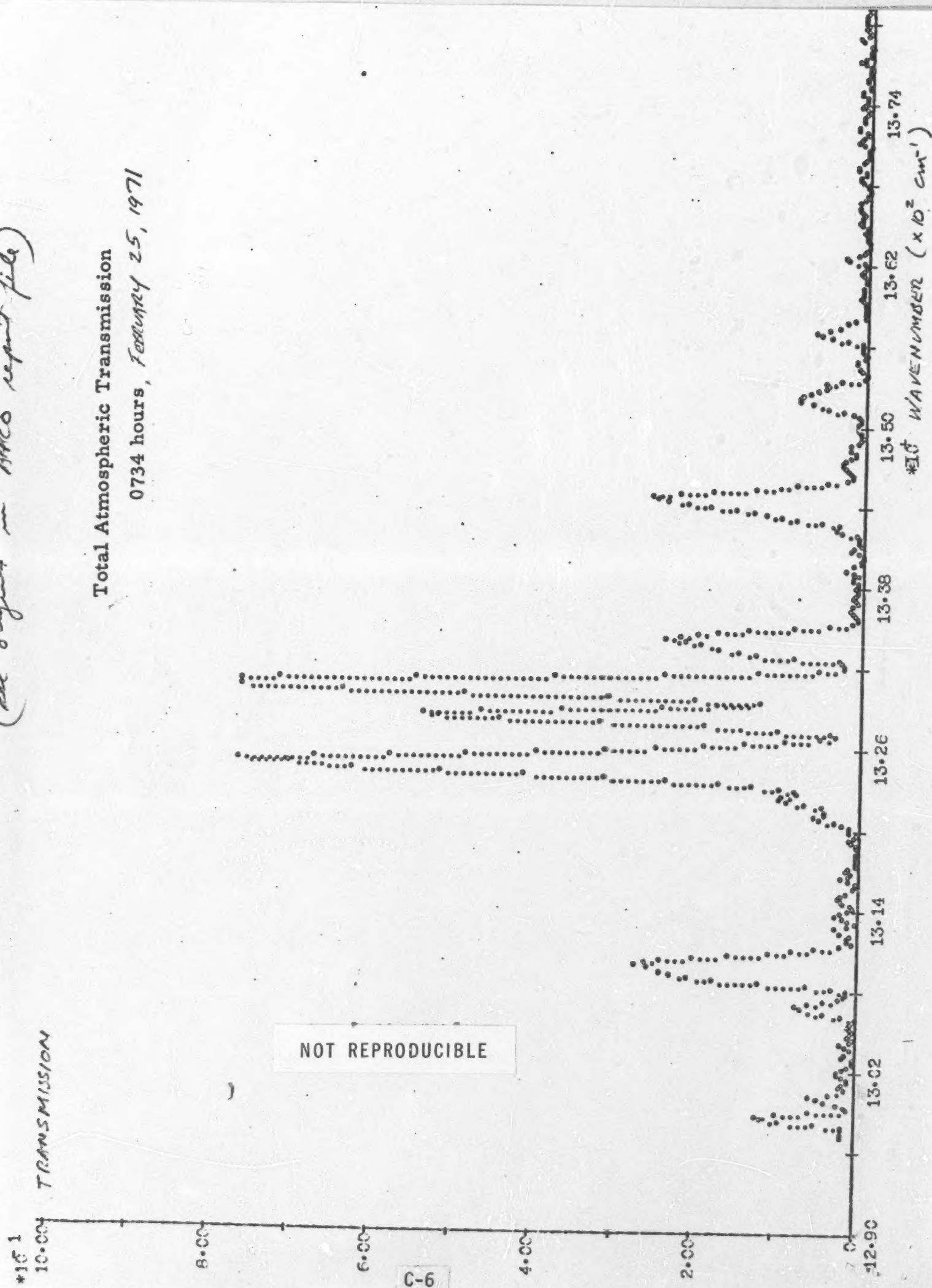
C-5

C-5

(see original in HACO report file)

Total Atmospheric Transmission

0734 hours, February 25, 1971



*10¹
10.00 TRANSMISSION

Total Atmospheric Transmission

0722 hours, February 25, 1971

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C-7

